THE WORLD OF CHEMISTRY

Program #18

THE CHEMISTRY OF EARTH

Producer John Ketcham

Air Script: October 31, 1988

PRODUCED BY

EDUCATIONAL FILM CENTER
and
THE UNIVERSITY OF MARYLAND

THE WORLD OF CHEMISTRY

Program #18: The Chemistry of Earth
Producer John Ketcham
Air Script: October 31, 1988

Annenberg/CPB Project Logo and Music

Funder Credits

MONTAGE: Valley, lava flows, volcanos, miners, computer chips

NARRATOR (MUSIC and NAT SOUND under):
Look at any corner of our planet and it looks like it's been there forever, but the earth is dynamic, it's been continuously changing for four and a half billion years. The earth's chemicals have been mixed, separated, and deposited unevenly throughout the globe. The earth's surface is different from its interior. Why? And what are the forces that redistribute the elements and minerals? Rare and valuable minerals can be found in a few widely scattered areas. Scarcity inspires a search for substitutes, and today our advancing technology can find new exotic uses for the most common of substances. Both our past and our future is rooted in the chemistry of earth.

SUPER: THE CHEMISTRY OF EARTH

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH next to globe

ROALD HOFFMANN (SYNC):
The American philosopher and historian, Will Durant, observed civilization exists by geological consent. Think about that. Since everything that we use ultimately derives from the earth, the geographical distribution of minerals and ores determines directly global economics, politics, patterns of trade. Here is a sample of stainless steel. An important component in it is the metal chromium. Chromium is also used in alloys that make hub caps and jet engines. And where does chromium come from? From ores from deposits that are found mainly, as are those of platinum, as are diamonds, in South Africa, or in the Soviet Union. Another strategic metal, tin, is found mainly in Southeast Asia. There is oil under Saudi Arabia. There is very little oil under Israel. How did valuable minerals come to be in one place and not another? Well, there's a lot that we don't know about this yet. (cont.)

ROALD HOFFMANN cont:
We don't know why one part of the globe was chosen to be rich in chromium and not another, but we've learned a great deal about how nature concentrates minerals, how it does it on the floor of the ocean, or on the top of land. We've learned about how ore deposits are formed, the underlying chemistry of this planet.

MONTAGE: African bush veldt, mining shots, English ruins, rock blasting, construction machinery

NARRATOR (MUSIC and NAT SOUND under):
Here in the African bush veldt, an area the size of New England, located in Southern Africa, interesting chemistry has been at work. Just beneath the surface lies some of the world's richest deposits of platinum, rhodium and chromium. A mineral is a naturally occurring substance with a characteristic chemical composition. When minerals are concentrated and are economically valuable, they're called ores. Because some places are rich with ores and minerals, like South Africa, and others are not, the fortunes of whole countries, of people and their governments, can rise and fall based on the wealth found in their natural treasuries. (cont.)

NARRATOR cont:
Since prehistoric times, we have recovered and used a variety of minerals. How did our ancestors obtain the minerals and elements they needed from the earth? One of the early techniques used in this ancient tin mine in Cornwall, England, was to build large fires at the base of the rock cliffs. The intense heat cracked the rocks, exposing the tin ore, which was then mined. Today we use dynamite and ammonium nitrate to blast rock away from ore-rich veins. But while we blast and drill and probe at the earth, whatever we're able to extract is limited by our technology, our needs at the time, and cost. How have the minerals and elements come to be located where they are? To find out, we must begin at the beginning, billions of years ago.

GRAPHIC: Formation and differentiation of Planet Earth

NARRATOR (MUSIC under):
Scientists believe that within the swirling dust of the primordial cloud, chemical reactions were occurring. Most of the elements and a variety of minerals were there. Some minerals were decomposing, and others were forming. Gravity was drawing the planet together. Initially, the earth was a homogeneous sphere. (cont.)

NARRATOR cont:
In time, because of the natural radioactivity of some of the elements deep within the earth, the temperature rose, and iron, one of our most common elements, melted and sank to the center of the earth. The earth's core was forming. This was the beginning of differentiation. Different rocks and minerals began emerging from the single homogeneous sphere. Lighter molten materials floated up to the surface, where they cooled to form a primitive crust. The earth was becoming a layered planet, with a dense iron core in the center, just above it the mantle, which is composed of dense silicates, and a crust of lighter rocks and minerals.

GRAPHIC: Element abundance bar chart

NARRATOR (MUSIC under):
The whole earth itself is rich with iron and oxygen, silicon and magnesium, and minor amounts of other elements. But we can only conveniently obtain the elements which are abundant in the crust. Generally, the abundances in the crust are different from the whole earth, as this graph shows. Notice, only about six percent of the earth's iron is in the crust where we can mine it. The rest is at the earth's core. (cont.)

NARRATOR cont:
On the other hand, there are large numbers of combined oxygen, silicon, and aluminum in the crust.

Cliffs, volcano, lava flows

NARRATOR (NAT SOUND under):
But minerals aren't evenly distributed across the earth. In a few scattered places, rare and valuable elements have been concentrated. How? Ore deposits form in three basic ways. One way is by the crystallization of magma, molten rock, in huge chambers beneath the earth's crust. The magma rises and comes in contact with cooler rock near the surface. Dr. Phillip Candela.

INTERVIEW: Dr. Phillip Candela, University of Maryland

SUPER: Phillip Candela

DR. PHILLIP CANDELA (SYNC):
It loses heat to the surrounding cold rock and, therefore, it begins to crystallize. Now, when this molten rock begins to crystallize in the subterranean chamber that we call a magma chamber, there's not just one chemical substance crystallizing, but sometimes five to ten different chemical substances are crystallizing out of this molten rock.

Shots of lava flows, mining, geysers, hot springs

NARRATOR (NAT SOUND under): Scientists believe that magma originates within the mantle itself. When conditions are right, the solidifying rocks can contain elements like chromium and platinum. This must have been the case in the bush belt of South Africa, where the ore deposits formed are both profitable and internationally strategic. The second way which mineral ore deposits form is through the action of superheated water. Deposits of tin, lead, and zinc minerals usually originate this way.

INTERVIEW: Dr. Phillip Candela cont.

DR. PHILLIP CANDELA (SYNC/VO): As this hot water is rising, it dissolves metals, it can dissolve sulfur from the surrounding rock, and as this water rises to cool the levels within the earth's crust, it loses heat to the surrounding rock.

Shots of geysers and hot springs

Also, this rising fluid can boil the metal and sulfur dissolved in the water can combine to form sulfide minerals. These sulfide minerals may plate themselves along the walls of a fracture and form a mineral vein.

INTERVIEW: Dr. Phillip Candela cont.

For example, here we have a mineral vein. This is a granitic type of rock here that obviously had fractured. Hot rising fluids filled the fracture. Dissolved in that water was silicon dioxide, which precipitated out from the solution to form crystals of quartz, which is some of the clear glassy material within the vein. Also the solution contained a metal called molybdenum, and also contained sulfur. And, upon cooling, the molybdenum and sulfur united and precipitated from the solution, along the walls of the vein, to produce a vein which we now find in this rock of molybdenite, molybdenum disulfide and silicon dioxide, or quartz.

Geysers, hot springs, black smokers

NARRATOR (MUSIC and NAT SOUND under):
Scientists think beneath these geysers and hot springs, ore deposits may be actively forming. These hydrothermal vents are also common on the ocean floor. This is a black smoker, a geyser at the bottom of the sea. While we have just recently been able to see them up close, they are already yielding new clues about how ore deposits form. It's a fascinating process.

GRAPHIC: Hydrothermal ore genesis

NARRATOR (MUSIC under):
At the oceanic ridges, running north and south, in the Mid-Atlantic, and in the Pacific, hot magmas are pouring out, renewing the earth's crust. As these magmas cool, they contract and crack. Ocean water then penetrates down to the molten magma. The water heats and it rises. Sulfur and metallic compounds from the adjacent rocks dissolve in the rising water, and they react. When the hot mineral-rich solution comes in contact with the cooler waters, a temperature difference of nearly 400 degrees, minerals precipitate out, often collecting in the cracks and fractures of the rocks.

INTERVIEW: Dr. Phillip Candela cont.

DR. PHILLIP CANDELA (SYNC):
They gave us direct visual proof that our ideas of the circulation of water around magma chambers and the stripping of metals from surrounding rocks, actually is a valid process in the formation of hydrothermal ore deposits.

River sedimentation

NARRATOR (NAT SOUND under):
The third process by which ore and mineral deposits form is sedimentation. Sedimentation is a physical, not a chemical, process.

DR. PHILLIP CANDELA (VO):
Bits of rock and mineral matter can be carried by flowing water. In areas where the velocity of water has decreased, the particles of rocks and minerals that are carried by the flowing water may settle out.

Rock quarry, building construction, ancient Greek buildings

NARRATOR (NAT SOUND under):
Because they are at the surface, and because they are relatively soft, sedimentary rocks have been mined, cut, and shaped throughout civilization. In many ways sedimentary rocks have shaped our history. Our cities were built with them. We make roads, skyscrapers, and statues of limestone and marble. Our ancestors built with it, too. They wanted their buildings to last, so they used rock. They couldn't have known the chemical environment would change to conspire against them.

DS in lab

DON SHOWALTER (SYNC):
Here we have a couple of pieces of common sedimentary rock. They're limestone. They're both made of calcium carbonate. This limestone came from Indiana. This one is Italian marble. Again, both of them calcium carbonate. (cont.)

DON SHOWALTER cont:
Now, we've used that material to build buildings, to make monuments, statues. But we have a problem now in modern day. Certainly you've heard of acid rain. On acid rain, the problem with that is the acid will react with that calcium carbonate, with that limestone, and cause deterioration of that substance. Let's do a test and I can show you how that works. What I'm going to do is add a little hydrochloric acid to the limestone. Now, geologists use this as a test for limestone, because you'll see why, there's certainly a reaction. Put a little bit of acid right on the limestone. Watch what happens. Oh, see the bubbles coming off of that? Now, here's the marble piece, Italian marble. It does the same thing. Of course it should, they're both calcium carbonate. The reaction now that is happening is that the calcium carbonate reacting with the hydrochloric acid, to produce carbon dioxide gas given off, as well as some water, and it's left then with some calcium chloride, some salt that's left on there.

MONTAGE: Buildings and sculptures in Venice, Italy

NARRATOR (MUSIC under):
Limestone and marble have always been important building materials, but they are both calcium carbonate. These sculptures and renaissance buildings in Venice, Italy, are priceless treasures from our past. Because they are made out of marble, the past is crumbling before our eyes. These works of art are being exposed to acid rain, which reacts with the calcium carbonate, turning these sculptures into soluble calcium salts.

MONTAGE: Plants, caves

NARRATOR (MUSIC under):
The same chemical reaction involving acidic rain and calcium carbonate, has been going on naturally for millions of years. It's how caves are formed. Although carbonate minerals are nearly insoluble in water, they are readily dissolved by the carbonic acid which is in the ground water.

EQUATION

As this diluted carbonic seeps through the joints of the rock formations, the limestone can be dissolved away. Over time, a cave is made. In this reaction, an equilibrium is reached. Calcium carbonate and bicarbonate exist together in the solution. It's a reversible reaction, which we can duplicate in the lab.

DS in lab

DON SHOWALTER (SYNC):
What if I took some of this calcium oxide, calcium carbonate minus the carbon dioxide, and put it into this distilled water, just plain water. You form a cloudy solution of calcium hydroxide. Now, what could we do with this in an interesting way? Now, there's another process that goes on here. What if I took this solution, poured it through the filter paper there. I would then have a solution of calcium hydroxide, or really, a solution of calcium oxide, if you look at it that way, too. One of the things I can do, I can add that carbon dioxide back onto there. Let's see if I can add it back on. So I can take that filtered -- I already did the filtering process for you -- take some of this filtered solution of calcium oxide, really calcium hydroxide, a base, and blow into it. Now, I'm not gonna drink it, am I? I'm gonna blow into there. So blowing in means now that I'm adding carbon dioxide. We breathe in oxygen, we breathe out carbon dioxide. Watch what happens.

EQUATION

There it goes. Now, the cloudiness is calcium carbonate. I put the CO2 back on to that calcium oxide. Now, let me speed this process up a little bit for you by adding in some dry ice. (cont.)

DON SHOWALTER cont:
The ice is solid carbon dioxide, so it's a more concentrated form. Put that in there. I want to put quite a bit of it. So initially what you will see is that solution getting more cloudy, forming more calcium carbonate. But there's an interesting phenomena that occurs, and what that is is that bicarbonate will be formed.

EQUATION

Now, the bicarbonate is soluble. It will dissolve in the solution. And hopefully we'll see it clear up. Now, this process that we've talked about is a reversible process. We've shown a little bit of that, calcium oxide into a water solution, and then we can add the carbon dioxide back into there. Oh, look, it has cleared up. So now that we see that the bicarbonate must have been formed. This sounds like a fairly complicated procedure, but it's really not that complicated. In fact, nature does this very, very well underground.

Mammoth Cave, Kentucky,
desert shot

NARRATOR (MUSIC and NAT SOUND under):
Here in Mammoth Cave, Kentucky, the same natural processes we saw in the laboratory are at work. Wherever the water drips, stalagmites form on the cave floor, and stalactites form on the ceilings around the source of the dripping water. The building process is slow. It takes over 100 years to form a single inch of a stalagmite or a stalactite. Another common compound, like calcium carbonate, which forms sedimentary rock and is found nearly everywhere, is silica, silicon dioxide or, as we know it, sand.

RH at quarry

ROALD HOFFMANN (SYNC):
Sand. It not only feels good between my toes at the beach or running through my fingers. What a simple material, and thousands of years of use. What is sand? Sand is quartz, finely divided, and quartz is a compound of silicon and oxygen, bound extremely strongly together. And it's only in this century that we've learned how to break apart that bond efficiently and economically, and to make large quantities of pure, very pure silicon. It's changed our lives. The silicon revolution is only 40 years old. Isn't it ironic, the new information age being shaped from simple sand?

Desert shots

NARRATOR (NAT SOUND under):
Sand. It's even more common than limestone. It contains two of the most abundant elements on earth, silicon and oxygen. Pure silicon doesn't exist in the elemental state, and it's been only recently we have been able to extract the silicon from the silicon dioxide.

MONTAGE: Computers and their parts

NARRATOR (MUSIC under):
The new revolution of silicon technology has been built on these discoveries. If silicon and oxygen are the two most abundant elements in the earth's crust, how do they combine with each other to form a variety of substances, and what structure do they have?

GRAPHIC: Silicate structure

NARRATOR (MUSIC under):
A look at the basic structure of a silicate reveals a silicon atom covalently bonded to four oxygen atoms, forming a tetrahedra, with the silicon in the center. This is the basic unit of silicate minerals. Two tetrahedra can link together by sharing an oxygen atom. A chain starts to form, as two oxygen atoms are shared by two silicon atoms. (cont.)

NARRATOR cont:
This chain is the unit in fiber silicates, like asbestos. Two chains might link together with every other silicon sharing oxygen atoms. And the chains can now link up, using the silicon-oxygen-silicon bonds. Sheets form, as in the structure of mica. The sheets can then stack one on top of another. Now each of the tetrahedra share all oxygen atoms with other tetrahedra, forming a three-dimensional framework like quartz. The length of the bonds between the silicon and the oxygen atoms are all the same. On this atomic scale, it's a symmetrical structure of indefinite length. Silicates are hard to melt. The covalent silicon-oxygen bonds are strong. To extract elemental silicon out of quartz, one has to mix it with carbon and heat it to a high temperature. But the silicon obtained that way still isn't pure enough for application in today's technology of chips and solar cells.

Exterior: AT&T Bell Labs, archival photograph of William Pfan

NARRATOR (NAT SOUND under):
AT&T, Bell Labs, in Short Hills, New Jersey. It was here a scientist named William Pfan advanced the technique of purifying silicon, called zone refining.

Dr. Winslow walking down hallway

DR. FIELD WINSLOW (VO):
We had a remarkable collection of brilliant people here when I first showed up on the scene in '45.

Dr. Winslow with lab worker

NARRATOR (NAT SOUND under):
Dr. Field Winslow is an organic chemist.

LAB WORKER (SYNC):
We have to seal off the tube with a monomer in the next couple hours before it explodes.

NARRATOR (NAT SOUND under):
Although not directly involved in the semiconductor project, he remembers the day William Pfan came into his office.

INTERVIEW: Dr. Field Winslow, organic chemist, AT&T Bell Labs

SUPER: Field Winslow

DR. FIELD WINSLOW (SYNC):
Came up to visit me one day and said he had this new idea, that what I want to do is to purify silicon and germanium by placing these materials in a boat and sweeping a hot zone repeatedly over this boat, so that you melt the material in the boat in zones, and sweep these zones along the length of the boat, and repeat it. And in the hopes of driving the impurities ahead of this hot zone.

Archival photographs of William Pfan

NARRATOR:
The principle William Pfan employed was, when a liquid solidifies, the crystal doesn't easily incorporate foreign materials. As a result, the impurities concentrate in a liquid zone.

INTERVIEW: Dr. Field Winslow cont.

DR. FIELD WINSLOW (SYNC):
And the object is that when this silicon resolidifies, the impurities in this molten zone are pushed ahead of the solidifying material. And each time more and more of the impurities are swept toward one end of the boat.

Archival footage and photographs of work at Bell Labs, transistor, silicon crystal pulling, computer chip

NARRATOR (MUSIC under):
Bell scientists knew the electrical properties of silicon depended on its purity. They knew if they could obtain pure silicon and then dope it, that is, add trace amounts of other elements to it, they could precisely control its conductivity. As a result of Pfan's work in purifying silicon, it became possible to design and build transistors which replaced the vacuum tube. That was nearly 40 years ago. Techniques have changed. Now they pull silicon crystals, slice them up, and then dope them with small amounts of the trace elements. In this way, changes in technology and demand can, in turn, change our needs for different elements and their minerals.

SUPER: THE CHEMISTRY
OF EARTH

MONTAGE: African bush veldt, lava, volcanos, black smokers, river sedimentation, quarry, Venetian sculptures, cave, desert, pulling crystals, computer board

NARRATOR (MUSIC under):
To review: We live on a dynamic planet, and the differentiation of materials in the planet is still occurring. The elements and minerals found at the earth's core are different than those found at the surface. And different chemical compounds and minerals are still being formed and deposited in widely scattered places. The three processes at work are magmatic action, where minerals are crystallized out in underground chambers of molten rock; hydrothermal action where, from superheated water, chemical compounds are deposited; and sedimentary action, where, through physical rather than chemical processes, rivers and streams transport minerals and deposit them in new areas. One of the common sedimentary rocks is limestone, calcium carbonate. It's been used throughout civilization as building material, but acidic rain reacts with the calcium carbonate, turning ancient works of art into calcium salts. The same reaction is responsible for caves. (cont.)

NARRATOR cont:
Another common substance, sand, has only recently been put to a more exotic use than building. By first obtaining silicon from the silicon dioxide and then purifying it, the information revolution was made possible.

RH at quarry

ROALD HOFFMANN (SYNC):
This quarry is a symbol of our dependence on the earth. We take from it its riches, some given to us simply like sand, some that have to be torn from its innards, like the rock or iron ore, some that are released by our ingenuity, like silicon. We are very successful at what we do, and so I don't doubt for a minute that under your feet there is another technological revolution waiting to be released by your hands, by your mind. But there is more, and this quarry also symbolizes that. The earth, the oceans, the atmosphere, we ourselves have been part of a grand enterprise, a living planet. It's not been a static one, it's changed. Remember those marvelous cycles of carbon dioxide, of water that we talked about in an earlier program? They've evolved with time. (cont.)

ROALD HOFFMANN cont:
But then we come on the scenes, masters of transforming a technology, and we have modified the cycles, not just one of them but many of them, and we intrude on them with a chemical shock, with a perturbation that is introduced in the geological equivalent of a blink of an eyelid, a mere 100 years or so. The perturbations that our civilization, our culture, have introduced to the earth may exceed the repair mechanisms that this marvelous organism, chemical system, has evolved for itself. This excellent canopy, our home in matter and in spirit, it deserves our best.

Credits, Closing Montage, Closing Music

Copyright © 1988
Educational Film Center
and The
University of Maryland

The World of Chemistry Logo

A Production of
UNIVERSITY OF MARYLAND
AND
EDUCATIONAL FILM CENTER

The Annenberg/CPB Project Logo

Funder Credits

1-800-LEARNER

PBS Logo